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Strip tillage width effects on sunflower seed emergence and yield

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ABSTRACT

Strip tillage is a conservation practice in which narrow strips, generally totaling less than 50% of the field area, are tilled. We hypothesized that strip tillage would be beneficial for long-term soil quality improvement, erosion control, and environmental protection because it also protects crop residues so they can cover and continuously protect the soil surface. A two-year field experiment with three replicates was conducted to quantify effects of three strip widths on selected soil physical properties, seed emergence and yield of sunflower (*Helianthus annuus*). A powered row crop rotary hoe which is a group of narrow rotary tillers spaced evenly along the width of the toolbar and powered by the tractor power take-off was used to till soil in strips. The rotary hoe was equipped with C-type blades and was used to till strip widths of 37.5, 30 and 22.5 cm by changing the blade position and number of flanges on each row of the rotary hoe. A constant rotor rotational speed (370 rpm), forward tractor speed (5.4 km h^{-1}) and tillage depth (10 cm) were used to create the three strip widths that corresponded to tilled zones encompassing 50, 40, and 30% of the field area, respectively. A pneumatic seeder with 75 cm row intervals was used for planting. The results show that as strip width increased, soil temperature increased but soil moisture content decreased due to evaporation loss from the tilled surface of the strips. Sunflower seed emergence ranged from 67 to 93%, with the lowest levels occurring with 22.5 cm strips. Plant length and stalk diameter also increased as strip width increased. Seed yields for the two years also increased with strip width, averaging 4.4, 4.1, and 3.9 Mg ha^{-1} for the 37.5, 30 and 22.5 cm strip widths, respectively. Based on these results, although seed yield was least for the 22.5 cm strip width, tractor fuel efficiency was greatest for that width and the soil tended to retain more moisture for that width, compared to the 30 and 37.5 cm widths, so the 22.5 cm strip width is recommended to the eastern Turkey.

1. Introduction

Conservation tillage is a generic term defined as any tillage and planting system that after planting maintains a minimum of 30% crop residue cover on the soil surface to reduce soil and water loss (ASAE Standards, 2006). Specific examples include minimum tillage, no-till, strip till, ridge till and mulch till. Soil and water protection is achieved by maintaining crop residues, to partially cover and protect the soil surface. The net results include improving soil moisture status, yield or productivity (Fortin, 1993) and soil water quality (Baker and Laflen, 1983; Kettler et al., 2000). It can also reduce input costs and labor needs (Tebrugge and During, 1999). The effectiveness of conservation tillage on water-use efficiency and grain yield depends on several factors including soil type, crop requirements, rainfall probability, and soil water-storage capacity (Boone, 1988; Lampurlanes et al., 2002).

Global adoption of conservation tillage has been gradually increasing in response to concerns regarding the impact of agricultural production on the environment. Use of conservation tillage practices frequently reduces the negative impacts associated with conventional tillage systems which include energy use, soil erosion, leaching and runoff of agricultural chemicals, and carbon emissions (Uri, 1999).

Subtle differences in the various forms of conservation tillage can be summarized as follows. Minimum-tillage simply embraces fewer passes and minimal soil disturbance in comparison to traditional tillage. No-till systems create only a very narrow slit in the soil for planting and fertilizer application (Morrison, 2002). Strip tillage is relatively new, having been first evaluated in the early 1990s. It offers a unique opportunity to apply nutrients and prepare a narrow tilled seedbed in one operation. Strip tillage thus offers a potential solution to several problems associated with no-tillage, especially late seed emergence due to cool and wet soil

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conditions. The tilled zone enhances evaporation of water from soil and warming of the seedbed while minimizing total soil disturbance (Licht and Al-Kaisi, 2005).

Strip tillage for row crops can be beneficial for long-term soil quality improvement, erosion control, and environmental protection (Morrison, 2002; Luna and Staben, 2003). It combines the benefits of no-till and full-width tillage by creating narrow tilled areas that provide a good seedbed condition while leaving the inter-row space undisturbed and covered with crop residue. The tilled zones generally encompass less than 50% of the total field area, especially when they are only 15–30 cm wide (Luna and Staben, 2003; Licht and Al-Kaisi, 2005). By preserving crop residues to partly cover and continuously protect the soil surface, soil and plant-available water are increased, infiltration is enhanced, soil compaction is reduced, and machinery, fuel and labor costs are lowered (Luna and Staben, 2003; Anon., 2004).

In recent studies, Opoku et al. (1997) found that corn grain yield with strip tillage was higher than with no-till, and similar to conventional tillage which included moldboard plowing + disc harrowing. Wysocki (1986) reported crop yields were about 3% lower with strip tillage than conventional tillage. Lowther et al. (1996) suggested that strip tillage was the ideal method for pasture renewal, while Cruse (2002) found that slight corn production increases with conventional tillage were not sufficient to offset differences in total production costs, which were lower with strip tillage. Similarly, Mullins et al. (1998) determined that strip tillage increased corn silage and grain yield by 14 and 30%, respectively, when compared to conventional tillage, while Lamm and Aiken (2007) reported that conventional tillage increased corn yield by 5 and 3% compared to strip tillage and no-till, respectively.

Temesgen et al. (2007) compared strip tillage, with and without subsoiling, to a traditional system involving a Maresha plow. Using total evaporation data, they found that strip tillage, followed by subsoiling, resulted in the least surface runoff, highest transpiration, highest grain yield and highest water productivity. However, according to Morrison (2002), there is no need for deep tillage in a strip tillage system because shallow tillage is sufficient to increase corn yield just as much as deep tillage.

Celik and Altikat (2010) compared effects of various strip tillage widths on seedling emergence, plant growth and yield of silage corn. They determined that greater strip width increased soil temperature, seedling emergence, plant height and the silage yield, but also increased evaporation from the soil, resulting in lower soil moisture content. Bosch et al. (2005) reported that runoff with conventional tillage was 81% greater than with strip tillage. With regard to selected soil quality indicators, Bilen et al. (2010) found that increasing strip width in strip tillage increased soil CO_2–C fluxes and bacteria population, but decreased fungi population and soil bulk density.

Licht and Al-Kaisi (2005) reported that strip tillage accelerated the soil moisture loss a little more than no-till, but the primary difference was that it increased soil temperature by as much as 1 to 1.4 °C in the top 5 cm. Increases in soil temperature, particularly in poorly drained soils, can be beneficial when soil moisture conditions remain relatively near field capacity, although increases in soil temperature can be limited by excessively wet weather conditions. Overall, strip tillage appears to be best suited to poorly drained, wet, cold soils where seed germination is delayed. Strip tillage helps dry and warm the soils in the spring, easing planter operations and promoting seed germination (Al-Kaisi and Hanna, 2002). Strip-tillage thus has the potential to increase soil temperatures in-row while using inter-row residue cover to conserve soil moisture for plant growth and development.

Strip tillage is still a fairly a new tillage technique in Turkey, but is a simple, practical and effective form of conservation tillage that can be easily applied to various crops including sunflower. It has the potential to increase soil temperature in tilled strips which is important for seed emergence and plant growth in Eastern Turkey. Strip tillage also uses inter-row residue cover to conserve soil moisture for plant growth and development and reduces input costs. Strip width can be varied mechanically with specialized equipment, but little research has been done to determine optimum strip width for sunflower seed emergence and growth.

Sunflower has become one of the most important oilseed crops in Turkey during the past 30 years (Kaya et al., 2007) and is also important in many other locations around the world. This crop offers advantages in crop rotation, is highly adaptable to dry conditions, suitable for mechanization and generally has low labor input. Recognizing the increasing importance of sunflower, our objectives were to investigate effects of various strip tillage widths on selected soil physical properties, seed emergence, yield and yield components of this crop.

2. Materials and methods

Field experiments were conducted in 2008 and 2009 on a loam soil at the Agricultural Research Center of the Ataturk University at Erzurum, Turkey. The experimental site is 1800 m above sea level with nearly level topography. Precipitation, which occurs mostly during the winter and spring months, totaled 318 and 438 mm in 2008 and 2009, respectively (Anon., 2011). Mean annual temperature (1975–2010) is 5.4 °C, with monthly temperature ranging from −9.9 °C in January to 19.4 °C in August (Fig. 1). Some important pre-planting physical properties in the top 10 cm of soil at the experiment site are presented in Table 1.

The treatments consisted of three strip widths [37.5 cm (ST1), 30 cm (ST2) and 22.5 cm (ST3)], creating tilled zones that covered 50, 40 and 30% of the field area, respectively. A powered row crop rotary hoe, equipped with C-type blades (so named because they appear to be shaped like the letter "C" when viewed from the side) and powered by the tractor power take-off, was used to till soil and create the various strip widths by changing both blade position on the flanges and the number of flanges on each row. The rotary hoe was used with a constant rotor rotational speed (370 rpm), tractor forward speed (5.4 km h^{-1}) and tillage depth (10 cm). The experiment was designed as a randomized complete block with three replicates. Each plot was 3 m by 30 m, separated by a 1.5 m by 30 m buffer.

A two-wheel drive Ford 5000 S tractor with a maximum power of 49.4 kW at a rated engine speed of 2100 rpm, was used for this study. The forward speed of the tillage operation was maintained constant by using a DICKEY-john RVS II type speed radar sensor (Dickey-John Corp., Auburn, IL, USA) on the tractor.

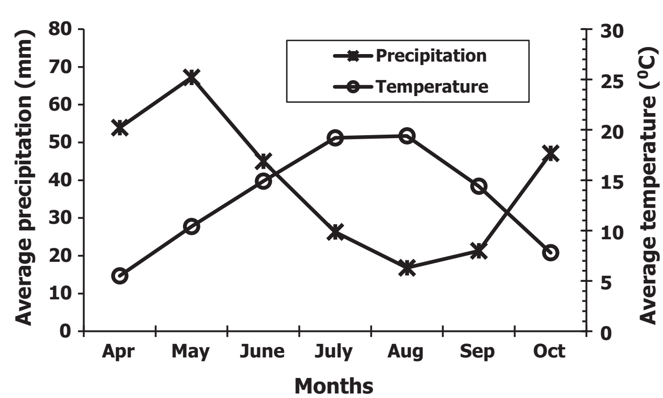

Fig. 1. Mean monthly rainfall and air temperature of growing season for 36-year average (1975–2010) at the experiment site (Anon., 2011).

Table 1
Initial soil physical properties for the 0 to 0.1 m depth range (mean of 2008 and 2009).

Physical property		Value
Bulk density ($Mg\,m^{-3}$)		1.17
Porosity (%)		56.06
Moisture content (% d.b.)		18.59
Penetration resistance (MPa)		1.29
Textural class		
Sand (%)	32.31	Loam
Silt (%)	44.12	
Clay (%)	23.57	

The strip tillage experiment with sunflower was conducted during two consecutive years (2008–2009) in a field with a sunflower–wheat (*Triticum aestivum* L.) rotation. Wheat was harvested with a combine at the end of August leaving a stubble height of 12 cm. No additional operations occurred until the second week of May (11th–15th) when tillage and sunflower planting commenced. Three replications of line-transect measurements of 50 m length with 10 measurement points were used to determine the percent residue cover after imposing the strip tillage treatments.

Sunflower was planted at a 5.5 kg ha^{-1} seeding rate using a four-row precision vacuum planter. The seed metering system was adjusted for a target seed spacing of 0.40 m in the row and 0.70 m between rows. The average vacuum level, hole diameter, and hole spacing in the metering disk for the vacuum planter were 6 kPa, 3.5 mm, and 12°, respectively (Celik et al., 2007). The rotary hoe treatments were applied before planting and the sunflower seeds were then planted in the tilled soil, so the centerline of each seed row was midway between the left and right edges of the tilled strip. The target planting depth was 40 mm. Sunflower seeds were of the Sirena hybrid oil seed variety (MayAgro Seed Corporation, Yildirim, Turkey). The weight of 1000 seeds, purity, and the germination rate were 148 g, 95%, and 96%, respectively. The experiment area was fertilized with a rate of 100 kg ha^{-1} N and 80 kg ha^{-1} P based on soil testing. Fertilizers that supplied 100% of the P and half of the N were applied at planting time, and the remaining N fertilizer was applied to all treatments when plant heights were between 25 and 30 cm.

One day after implementation of strip tillage treatments, two soil samples (each 5.0 kg) were taken from 0 to 100 mm depth of each plot to determine the distribution of the size of soil aggregates produced by the rotary hoe. The soil samples were air-dried for at least 30 days and then sieved into eight size fractions by using a set of sieves of <1, 1–2, 2–4, 4–8, 8–16, 16–32, 32–63 and >63 mm mesh openings. The set of sieves was shaken for 50 s using a frequency of approximately 50 Hz and oscillation of amplitude of 2 mm (Celik et al., 2011). A Retsch KS1000 sieving machine (Retsch GmbH., Haan, Germany) was used to shake the sieve set. The remaining aggregates on each sieve were weighed and the aggregate mean weight diameter (MWD) for each soil sample was calculated using the following equation (Gee and Bauder, 1986):

$$\mathrm{MWD} = \sum_{i=1}^{n} \bar{X}_l * W_i$$

where MWD is the aggregate mean weight diameter in mm, $\bar{X}_l$ is the mean diameter of any particular size range of aggregates separated by sieving in mm and W_i is the weight of aggregates in that size range as a fraction of the total dry weight of soil used.

Before strip tillage, the top 10 cm of soil in the field was sampled using 50 mm diameter by 50 mm high cylindrical soil samples to determine dry soil bulk density and initial soil moisture content. For measurement of soil penetration resistance, a standard analog cone penetrometer (60° circular cone, 100 mm^2 base area and 11.28 mm base diameter) was used. Penetration resistance measurements were taken six times in each plot from locations beside soil bulk density measurements. Readings were taken at 0–5 cm and 5–10 cm (tilling zone for ST1, ST2 and ST3) at each location following the procedure described in the ASAE Standards (1993). A second sampling for soil bulk density, penetration resistance and moisture content was made in the each plot after planting of sunflower. Seedbed temperature was measured every day at the same time at 6 mm depth in each of the treatments by a digital thermometer. Air and dew point temperatures of the experiment area were obtained from a weather station located near the field sites.

Mean emergence time (MET), emergence rate index (ERI), and percentage of emergence (PE) were determined using the following equations (Bilbro and Wanjura, 1982; Karayel and Ozmerzi, 2002):

$$\mathrm{MET} = \frac{N1*T1 + N2*T2 + \cdots + Nn*Tn}{N1 + N2 + \cdots + Nn}$$

$$\mathrm{ERI} = \frac{\mathrm{Ste}}{\mathrm{MET}}$$

$$\mathrm{PE} = \frac{100\%\ \mathrm{Ste}}{n}$$

where MET is the mean emergence time (day), ERI is the emergence rate index (seedling day m^{-1}), PE is the percentage of emergence (%), $N1\ldots n$ is the number of seedlings emerging since the time of previous count; $T1\ldots n$ is the number of days after sowing, Ste is the number of total emerged seedlings per meter. n is the number of seeds sown per meter.

At harvest, plants within the center two rows of each plot were harvested and sun dried for yield analyses. The heads were threshed manually and the number of seeds per head was counted. Stalk diameter of ten randomly selected plants was measured using a vernier caliper. Total aboveground biomass (kg ha^{-1}), seed yield (Mg ha^{-1}) and plant height (cm) were recorded. Roots were removed from the soil were rinsed with water to remove the soil, dried in the oven and weighed to determine root mass.

Data were analyzed statistically to test for differences among treatments. An ANOVA procedure was used to perform the analysis of variance, which was appropriate for a randomized complete block design. Means were separated by LSD when treatment effects were significant. Statistical significance was evaluated at $P \leq 0.05$. The data analysis for each year was separately performed after the combined analysis across years of the data was significant (Licht and Al-Kaisi, 2005).

3. Results and discussion

The average penetration resistances at different strip widths and sunflower growing seasons are shown in Table 2. In both years and for all strip widths, the penetration resistance increased with depth and the greatest resistance was always measured at the maximal measured depth of 20 cm, while the lowest values were measured at the tillage depth of 0–10 cm (Table 2). For each year and depth range, strip width did not significantly affect penetration resistance. The three strip widths were thought to have the same effect on penetration resistance because the same rotary hoe was used to prepare them. Penetration resistance was significantly reduced compared to the initial conditions. Specifically, the soil in the 0–10 cm tilled layer was loosened considerably by the rotary hoe blades, and the penetration resistance was relatively uniform throughout the 0–10 m profile for all strip widths ranging between

Table 2
Soil penetration resistance as affected by tillage method.

Tillage method	Penetration resistance (MPa)							
	2008				2009			
	Depth (cm)				Depth (cm)			
	0–5	5–10	10–15	15–20	0–5	5–10	10–15	15–20
ST1[a]	0.07a[b]	0.86a	1.05a	1.42a	0.05a	0.81a	1.18a	1.45a
ST2	0.06a	0.87a	1.12a	1.53a	0.05a	0.93a	1.17a	1.43a
ST3	0.06a	0.91a	1.17a	1.58a	0.06a	0.91a	1.18a	1.49a
P	0.871	0.722	0.384	0.164	0.540	0.054	0.694	0.377
SEM[c]	0.006	0.027	0.037	0.039	0.005	0.025	0.005	0.031

[a] ST1, strip width 37.5 cm; ST2, strip width 30 cm and ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean (MPa).

0.05 and 0.93 MPa. Penetration resistance was also reduced at the 0–0.15 m depth compared to before strip tillage, which was likely a result of the newly loosened and mixed soil in the upper soil layer, but was greater than before strip tillage throughout the 0.15–0.20 m profile. Penetration resistance tends to increase with an increase in soil bulk density. This is in agreement with previous investigators who reported that penetration resistance varies directly with bulk density. The relationship between soil moisture content and penetration resistance shows a decrease in penetration resistance as the soil moisture content increases which is in agreement with the results of several authors.

Similar to the penetration resistance, no differences in soil bulk density were found between strip widths at the 0–5 cm and 5–10 cm depths during the two sunflower planting seasons. Soil bulk density varied between 1.15 Mg m^{-3} and 1.21 Mg m^{-3} and was lower at the 0–5 cm depth in both years and for all strip widths (Table 3) compared to the initial soil bulk density value (1.17 Mg m^{-3}). This may be due to crumbling of soil and incorporation of crop residues which decreased the soil bulk density throughout the tilled layer of soil (Gangwar et al., 2006). The lower value of soil bulk density at the upper 0–5 cm layer clearly revealed the quality of seedbed preparation which allowed a greater amount of water to infiltrate into the soil and the sunflower to grow vigorously.

Change in soil moisture content is an important indicator in evaluating the strip-tillage effect on the soil environment (Licht and Al-Kaisi, 2005). In both planting seasons (11–15 May in 2008 and 2009), the initial available soil moisture content at the depth of 0–10 cm was adequate for seed germination, averaging 17.6 and 20.6% d.b. in 2008 and 2009, respectively. During the sunflower seed emergence period, soil moisture content was increased by rainfall (Fig. 2). Table 4 shows soil moisture content measured at the top 10 cm soil layer for four, two-day intervals starting one week after planting. According to the soil moisture measurements, untilled zones between strips, which were covered with residue, were more effective at conserving rainwater than if the zones between strips were tilled. Residue between strips reduces evaporation, and gives more time for the water to redistribute within the soil profile. Licht and Al-Kaisi (2005) and Schillinger (2005) also reported that higher amount of residue cover may help explain the trend for higher soil moisture contents in the 0–10 cm depth and provide potential soil and water conservation benefits. Strip widths (ST1, ST2 and ST3) did not differ significantly in their effect on seed-zone soil moisture content in 2008. The emergence period soil moisture content under various strip widths, however, was significantly different in 2009. The ST3 (22.5 cm strip width) treatment allowed more moisture to be conserved in the 0–100 cm depth compared to the ST1 and ST2 treatments. Soil moisture content increased as strip width decreased.

The data obtained from sieving were evaluated based on optimum seedbed aggregate size for crop production. The sieved soil was classified into three groups (<1 mm, 1–8 mm and >8 mm) as done by Celik (1998). The first group is not appropriate for a seedbed as this small size causes high bulk density and presents a risk for soil compaction and erosion. The third group often forms an uneven soil surface with large clods that need to be fragmented by secondary tillage to obtain a suitable seedbed. The second group (1–8 mm) is considered the best aggregate size for most crops as evidenced by several published sources (e.g. Jain and Agrawal, 1970; Baver et al., 1972; Heege, 1974; Logsdon et al., 1987; Adam and Erbach, 1992; Celik, 1998), although the optimum size may differ according to crop needs. In addition to these aggregate size groups, mean weight diameter (MWD) was used to evaluate the

Table 3
Soil bulk density as affected by tillage method.

Tillage method	Soil bulk density (Mg m^{-3})			
	2008		2009	
	Depth (cm)		Depth (cm)	
	0–5	5–10	0–5	5–10
ST1[a]	1.18a[b]	1.20a	1.16a	1.21a
ST2	1.18a	1.20a	1.15a	1.20a
ST3	1.17a	1.19a	1.16a	1.18a
P	0.909	0.914	0.952	0.264
SEM[c]	0.017	0.011	0.007	0.009

[a] ST1, strip width 37.5 cm; ST2, strip width 30 cm, ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean (Mg m^{-3}).

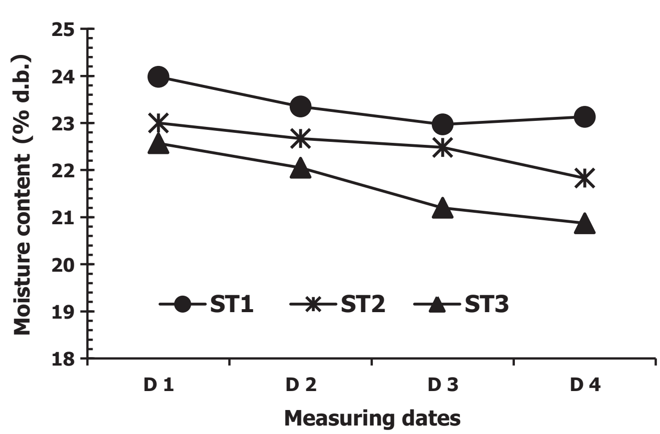

Fig. 2. Effects of strip width on soil moisture content at the top 10 cm soil layer for four selected dates (average of 2008 and 2009 season). The ST1, ST2, and ST3 denote strip widths of 37.5, 30, and 22.5 cm, respectively.

Table 4
Effects of strip width on soil moisture content at the 10 cm top layer, for four dates starting one week after planting, at two-day intervals.

Tillage method	Soil moisture content (% d.b.)							
	2008				2009			
	MC-1	MC-2	MC-3	MC-4	MC-1[d]	MC-2	MC-3	MC-4
ST1[a]	21.1a[b]	21.2a	21.3a	21.4a	24.0a	22.5b	21.7b	21.5b
ST2	21.7a	21.2a	21.5a	21.7a	24.3a	23.2b	22.6ab	22.1b
ST3	22.2a	22.8a	22.7a	22.5a	25.6a	24.6a	24.0a	24.2a
P	0.559	0.128	0.085	0.512	0.687	0.030	0.027	0.012
SEM[c]	0.271	0.433	0.313	0.232	0.616	0.346	0.373	0.445

[a] ST1, strip width 37.5 cm; ST2, strip width 30 cm and ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean (% d.b.).
[d] MC-1 through MC-4 are the first through fourth soil moisture contents determined after planting (% d.b.).

Table 5
Soil aggregate size distribution after seedbed preparation.

Tillage method	2008				2009			
	Proportion, by mass, of aggregates in size categories (%) Aggregate size (mm)			MWD (mm)	Proportion, by mass, of aggregates in size categories (%) Aggregate size (mm)			MWD (mm)
	<1	1–8	>8		<1	1–8	>8	
ST1[a]	33.3a[b]	28.1a	38.6a	12.1a	35.5a	28.3a	36.2a	11.4a
ST2	32.4a	28.9a	38.7a	12.3a	31.8a	29.3a	38.9a	12.5a
ST3	32.6a	28.3a	39.2a	12.5a	32.8a	28.2a	39.0a	12.6a
P	0.815	0.481	0.944	0.759	0.078	0.490	0.284	0.182
SEM[c]	0.533	0.356	0.583	0.152	0.662	0.414	0.745	0.255

[a] ST1, strip width 37.5 cm, ST2, strip width 30 cm and ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean (mm).

tillage systems for all soil aggregate sizes (Berntsen and Bere, 2002).

The rotary hoe operation that created most of the aggregates was the same for all strip widths, so as expected there were no significant differences in the proportion of soil in the <1, 1–8 and >8 mm classes in either growing season. In both years, the greatest proportion of soil was found in large aggregates (>8 mm) followed by the <1 mm fraction. In general, the average amount of soil in the >8 mm size fraction was approximately 15% and 25% higher than in the <1 mm or 1–8 mm fractions, respectively. The proportion of soil in the <1 mm size was approximately 15% greater than in the 1–8 mm fraction (Table 5).

Similar to the aggregate size distribution, no significant differences were found between strip widths for the MWD values (Table 5). However, the ST3 strip width had a greater proportion of fine aggregates in the seedbed, followed by ST2 and ST1, respectively.

The seedbed soil temperature was measured at midday in the top 6 cm layer of soil with two-day intervals from the first to the third week after planting. The average seedbed soil temperature under ST1, ST2 and ST3 strip widths show no significant differences during the seed emergence period (Fig. 3). However, the soil temperature associated with ST3 was generally higher than that of ST1 and ST2 at the time of day (12–14 h) when the air and soil temperatures reached a maximum. Generally, tilled soil has the advantage of much warmer and drier seedbeds due to pores allowing circulation of air, compared to residue-covered untilled areas. Tillage increases soil drying and heating because tilling produces a coarse soil surface, increases air pockets in which evaporation occurs, and ultimately accelerates soil drying and heating. Soil aggregates have lower heat capacity and greater heat conductivity than water, so dry soils typically warm and cool faster than wet soils (Licht and Al-Kaisi, 2005).

The ambient air temperature of the experiment area in the seed emergence time was relatively cool during the nights and relatively warm during midday. The seedbed soil temperature (0–5 cm depth) was higher than the temperature at depths greater than 5 cm deep, and this is very important for seed emergence (Licht and Al-Kaisi, 2005). As soil depth increases soil bulk density increases (Table 3) and thermal conductivity decreases (Cavalaris et al., 2003). During the seed emergence time, the midday temperature of undisturbed soil at the 6 cm depth (Fig. 3) was non-limiting and always above the typically recommended minimum values of day and night temperatures (21 and 12 °C, respectively) for sunflower (Theodore et al., 1997; Morrison and Sanabria, 2002).

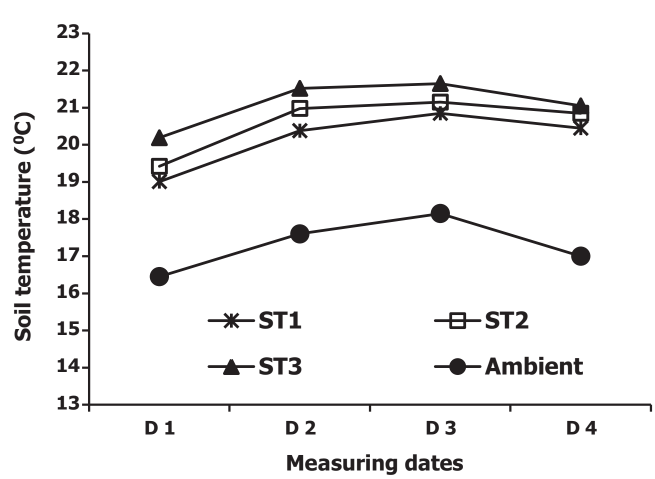

Fig. 3. Effects of strip widths on seedbed soil temperature of four selected dates (average of 2008 and 2009 season). 'Ambient' in legend indicates ambient air temperature.

Table 6
Analysis of variance (P values) and means comparisons for seed emergence values.

Tillage method	2008			2009		
	MET (day)	ERI (seedlings d^{-1} m^{-1})	PE (%)	MET (day)	ERI (seedlings d^{-1} m^{-1})	PE (%)
ST1[a]	17.6a[b]	0.123a	84.8a	15.7a	0.140a	93.3a
ST2	17.9a	0.107a	74.3b	15.7a	0.127b	84.8b
ST3	18.0a	0.100a	66.7b	15.8a	0.117c	80.0b
P	0.177	0.077	0.010	0.053	0.003	0.014
SEM[c]	0.082	0.004	3.12	0.020	0.004	2.15

[a] ST1, strip width 37.5 cm, ST2, strip width 30 cm and ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean.

Table 7
Yield of dry biomass, dry seed, plant height and stalk diameter in different strip widths for 2008 and 2009.

Tillage method	2008				2009			
	Total dry biomass (Mg ha^{-1})	Yield of dry seeds (Mg ha^{-1})	Plant height (cm)	Stalk diameter (mm)	Total dry biomass (Mg ha^{-1})	Yield of dry seeds (Mg ha^{-1})	Plant height (cm)	Stalk diameter (mm)
ST1[a]	28.2a[b]	3.9a	160a	26.3	28.4a	4.8a	177a	24.3a
ST2	24.1b	3.4b	151ab	23.3a	24.8b	4.7a	172ab	24.2a
ST3	22.9b	3.2b	143b	20.0a	23.6b	4.6b	166b	23.7a
P	0.001	0.012	0.023	0.248	0.011	0.013	0.015	0.871
SEM[c]	175	10.7	3.32	1.36	81.6	3.25	2.07	0.611

[a] ST1, strip width 37.5 cm, ST2, strip width 30 cm and ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean.

In 2008, there were no significant differences in MET and emergence rate index (ERI) between the three strip widths, while the effect of strip width on total PE was statistically important ($P < 0.05$). In 2009, MET was similar for the strip widths, however, ERI and PE were statistically important. The greatest total PE was 93.3% and occurred in 2009 for the ST1, while the lowest emergence was 66.7% and occurred in 2008 for the ST3. The average sunflower plant population for ST1, ST2 and ST3 were 3.06, 2.65 and 2.38 plants m^{-2} respectively, which are 14, 26 and 33% lower than the target seed rate (3.57 plants m^{-2}).

As strip width increased, PE and ERI increased and MET decreased in both years (Table 5). Average MET values were 17.82 days in 2008 and 15.74 days in 2009. It is expected that the increase in soil moisture content and soil temperature in the surface layer of seedbed in 2009 caused MET to decrease. Similar results were reported by Licht and Al-Kaisi (2005). As a result of this, it was observed that average PE in 2009 was approximately 15% greater and average MET was approximately 11% shorter than those in 2008 (Table 6).

The length of the vegetation period of the experiment location, is limiting for growing the oil seed type of sunflower. The sunflower seeds could reach maturity about 110 days after planting. Statistical differences in sunflower total biomass, dry seed yield and plant height were observed among strip widths in both 2008 and 2009. There was no significant difference in stalk diameter among the treatments in either 2008 or 2009 (Table 7). These results indicate that the sunflower total biomass, seed yield and plant heights were increased as strip width increased in both growing seasons. The highest values of total dry biomass, seed yield, plant height and stalk diameter were obtained in the ST1 strip width in both years. The

Table 8
Mean sunflower root mass, weed infestation, and soil moisture content.

Tillage method	2008			2009		
	Root[d] mass (g)	Weed[e] infestation (g m^{-2})	Soil moisture[f] c ontent (% d.b.)	Root mass (g)	Weed infestation (g m^{-2})	Soil moisture content (% d.b.)
ST1[a]	30.3a[b]	134.8b	21.5b	38.7a	117.4c	22.4b
ST2	26.0ab	138.3ab	21.8ab	36.7b	124.9b	23.0b
ST3	25.0b	144.1a	22.02a	36.0b	131.0a	24.6a
P	0.069	0.044	0.026	0.030	0.000	0.008
SEM[c]	1.03	2.3	0.133	0.455	2.06	0.340

[a] ST1, strip width 37.5 cm, ST2, strip width 30 cm and ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean.
[d] Average root mass per plant (g).
[e] The biomass of aboveground portions of weeds (g m^{-2}).
[f] Soil moisture content at the time of root sampling (% d.b.).

Table 9
Tractor fuel consumption for tillage methods in both years ($L\,ha^{-1}$).

Tillage method	2008	2009
ST1[a]	12.2a[b]	11.5a
ST2	11.5a	11.0a
ST3	9.2b	9.4b
P	0.001	0.002
SEM[c]	0.459	0.321

[a] ST1, strip width 37.5 cm, ST2, strip width 30 cm and ST3, strip width 22.5 cm.
[b] Means within the same column followed by the same letter are not significantly different according to LSD (0.05).
[c] SEM, standard error of the mean ($L\,ha^{-1}$).

yield of sunflower seeds in 2008 was lower compared with that of 2009 yield (Table 7). This was a result of greater precipitation and a higher emergence rate during 2009 than 2008.

The yield of dry sunflower seeds varied from 3.2 to 4.8 Mg ha^{-1}. Sun dried seeds had 10% d.b. moisture content. Average sunflower seed yields for the two years were 4.4, 4.1, and 3.9 Mg ha^{-1} for the ST1, ST2 and ST3 strip widths, respectively. The total harvestable biomass (dry matter) varied from 22.9 to 28.2 Mg ha^{-1}. Plant height and stalk diameter values had the same trend as the trend for the total biomass and seed yield values. The interaction between years and strip widths related to the yield and yield parameters was not important statistically.

The effects of strip width on weed infestation and soil moisture content were statistically important in both years (Table 8). As expected, the increase in strip width expanded the effects of tillage and decreased weed infestation on the tilled strips and on the residue-covered area between strips. Contrary to the weed infestation, the soil moisture content increased as strip width decreased. However, the moisture content of soil during seed emergence was enough for weeds to grow. The effect of weed infestation on the sunflower root mass was statistically important. The sunflower root growth decreased as weed infestation increased. Root growth and weed infestation data along with soil moisture content of sampling time are shown in Table 8.

One of the most important benefits of strip tillage which has been proved by many researchers is reduced fuel consumption. This is because strip tillage is a common conservation tillage practice that isolates tillage to a narrow strip and causes the tractor to have less load and therefore, reduced fuel consumption. The effect of strip width on fuel consumption was statistically important in both years (Table 9). As expected, the increase in strip width increased fuel consumption. In both years, the ST1 and ST2 treatments were statistically similar and had greater fuel consumption than ST3.

4. Conclusions

The results of this field study indicate that farmers can benefit from advantages of a strip tillage system by modifying the use of their existing rotary hoes to use them for strip tillage, in addition to using them for mechanical weed control. On the basis of this research we reached the following conclusions.

Strip width did not significantly affect soil penetration resistance and soil bulk density. The 22.5 cm strip width resulted in a greater proportion of fine aggregates in the seedbed followed by the 30 and 37.5 cm widths.

Residue between strips reduced water evaporation from the soil, and gave more time for the water to redistribute within the soil profile. Soil moisture content increased as strip width decreased and a 22.5 cm strip width conserved more moisture at the 0–100 mm depth compared to the 30 and 37.5 cm strip widths.

Soil temperatures at the top 5 cm soil layer for the 37.5, 30, and 22.5 cm strip widths showed no significant differences during the seed emergence period. However, the soil temperature associated with the 22.5 cm strip width was generally higher than that of the 37.5 and 30 cm widths at the time of the day (12–14 h) when the air and soil temperatures reached a maximum.

The greatest total percentage of seed emergence was 93.3% and occurred in 2009 for the 37.5 cm strip width while the smallest emergence was 66.7% and occurred in 2008 for the 22.5 cm width. The average sunflower plant populations for the 37.5, 30, and 22.5 cm strip widths were 3.06, 2.65 and 2.38 plants m^{-2} respectively, which are 14, 26 and 33% lower than the target seed rate (3.57 plants m^{-2}). As strip width increased, percentage of emergence and emergence rate index increased, and mean emergence time decreased in both years.

Sunflower total dry biomass, dry seed yield and plant height increased as strip width increased. The highest values of total biomass, seed yield, plant height and stalk diameter were obtained for the 37.5 cm strip width in both years. Average sunflower seed yields for the two years were 4.4, 4.1, and 3.9 Mg ha^{-1} for the 37.5, 30, and 22.5 cm strip widths, respectively.

An increase in strip width expanded the effects of tillage, increased significantly the sunflower root mass and decreased weed infestation. As expected, the increase in strip width also increased tractor fuel consumption.

Based on these results, although seed yield was least for the 22.5 cm strip width, tractor fuel efficiency was greatest for that width and the soil tended to retain more moisture for that width, compared to the 30 and 37.5 cm widths, so the 22.5 cm strip width is recommended to the eastern Turkey.

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